The long-term spectral stability of HgI_2 gamma-ray detectors

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ABSTRACT

An evaluation of the spectral performance of eight planar mercuric iodide (HgI_2) gamma-ray detectors under continuous bias voltage for a duration of up to 2000 hours has demonstrated the high degree of long-term stability of mercuric iodide as a radiation detector material. Spectral parameters determined in this evaluation include the %FWHM, the peak-to-valley and peak-to-background ratios, the gain stability of the full energy peak, and the preamplifier offset voltages. Isotopes with three distinct energies were used for these measurements: ^{137}Cs (662 keV), ^{57}Co (122 keV) and ^{241}Am (59 keV). The spectra were analyzed and spectral parameters were generated using Robwin$^{@}$, a spectral analysis program developed by Constellation Technology. Robwin$^{@}$ performs simultaneous non-linear fitting of several key elements of the spectrum, emphasizing the continuum for the entire spectrum, the photopeak response function of all lines in the spectrum, the relative intrinsic efficiency of the detector and the photopeak resolution width.

These findings provide further support for the widespread use of mercuric iodide as a room temperature semiconductor radiation detector material for energy spectrometry.

Keywords: mercuric iodide, room temperature semiconductor radiation detectors; gamma-ray detectors, life tests; %FWHM; peak to valley ratio; peak to background ratio; preamplifier offset voltage

1. INTRODUCTION

The development of mercuric iodide (HgI_2) as a radiation detector material at Constellation Technology Corporation (CTC) is motivated by the need for spectrometer grade, semiconductor radiation detectors that operate at ambient temperatures without cooling. Among candidate materials for room-temperature radiation detectors (e.g. cadmium zinc telluride, gallium arsenide, lead iodide) Constellation Technology HgI_2 possesses the highest intrinsic resistivity with values ranging from 10^{13} ohm-cm to 10^{14} ohm-cm. HgI_2 can therefore sustain higher bias voltages while generating lower detector leakage currents. High leakage currents cause high preamplifier offset voltages where non-linear response can distort detector signals. High preamplifier offset voltages that fall above or below operational amplifier rail voltages can in some cases result in damage to preamplifier components. In addition, when high leakage currents occur poor radiation detection signal to noise ratios are obtained, which limit detector performance.

The large atomic numbers of the two constituent elements in HgI_2 (mercury Z=80; iodine Z=53) in conjunction with a high density at 6.3 gm/cm^3 give HgI_2 the highest potential efficiency for absorption of higher-energy radiation events among the candidate room-temperature detectors. In order to capitalize on these superior attributes, the incentive exists for fabricating the largest possible detector areas & volumes. The high purity synthesis and purification processing of HgI_2 developed at CTC makes possible the physical vapor deposition growth of large, high structural quality, single crystals from which large area detectors are fabricated. HgI_2 gamma-ray planar 25 mm x 25 mm detectors with areas of 625 mm^2 and cross sections as thick as 3 mm are commercially available at specified resolution values as low as ~2% full width at half maximum (%FWHM) for ^{137}Cs (662 keV).

In order to support commercialization of HgI_2 gamma-ray detectors, an on-going test campaign was initiated at CTC to extend and enhance the detector test database. This test campaign includes evaluations of: 1. Spectral performance, long-term stability, i.e. life tests; 2. Elevated temperature spectral performance; 3. Detector AC capacitance; 4. Detector bias voltage

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on/off cycling; 5. Effects of shaping time using conventional nuclear instrumentation; 6. CTC electronics utilizing proprietary gated integrator technology; and 7. Electronic transport properties, a la $\mu\tau$ product determinations. This report presents results from the spectral performance long-term stability or life test phase of the program. Results from the evaluation of the effects of elevated temperatures on the spectral performance of HgI_2 radiation detectors will be reported elsewhere.[1]

2. EXPERIMENTAL DESIGN: 1000 & 2000 HOUR DURATION LIFE TESTS

In order to characterize the long-term spectral performance stability of HgI_2 as a radiation detector material, eight (8) Constellation Technology gamma-ray detectors were selected from inventory for evaluation. They were placed under continuous applied bias voltage and evaluated periodically for up to 2000 hours. Detectors from inventory are previously conditioned under bias, or "broken-in", for a period of at least 14 days. Selection was based on the detectors displaying "good" spectral performance after this period of polarization. Good spectral performance was equated with having a Resolution for ^{137}Cs (662 keV) less than 6% FWHM.

Detectors were also selected in two groups based on area: i.e. 25 mm x 25 mm (625 mm^2) and 10 mm x 10 mm (100 mm^2). Alternating current capacitance evaluations performed at CTC on nominally 2 mm thick detectors measured capacitance values of ~15 pF and ~5 pF respectively for these two detector areas. Detector dimensions and the initial bias voltage conditioned resolution values for three standard radiation sources, i.e. ^{137}Cs (662 keV), ^{57}Co (122 keV), and ^{241}Am (59 keV), are presented in Table 1.

Conventional nuclear electronics were used in generating the initial conditioned data and the life test results (eV Products 5093 charge sensitive preamplifier; EG&G/Ortec 672 shaping amplifier). The EG&G/Ortec 672 shaping amplifier was modified to provide longer shaping times, up to 24 μsec, which was used in generating data for ^{137}Cs (662 keV). For ^{57}Co (122 keV) and ^{241}Am (59 keV) shaping times of 8 μsec or 12 μsec were used. Spectral parameters were generated using Robwin@, a spectral analysis program developed by Constellation Technology Corporation.

3. EXPERIMENTAL RESULTS & CONCLUSIONS: 1000 & 2000 HOUR DURATION LIFE TESTS

Composite graphs of spectral performance parameters from the life tests are presented in Figures 1 through 14. %FWHM values for ^{137}Cs (662 keV), ^{57}Co (122 keV) and ^{241}Am (59 keV) are included in Tables 1 & 2 for comparison with initial conditioned values. The following comments summarize results and observations.

<u>For ^{137}Cs (662 keV):</u>

1. The resolution or %FWHM was stable over the 2000-hour test duration for seven of eight detectors tested. For the remaining one detector there was a slight degradation in resolution, i.e. the %FWHM slightly increased from ~5% FWHM at 1700 hours test time to ~7% FWHM at 2000 hours.

2. The peak-to-valley ratio was stable with time showing a slight overall, improving trend.

3. The peak-to-background ratio displayed slightly more variability with time than the peak to valley ratio. Nevertheless, the peak to background ratio also displayed a similar improving trend with time, indeed, slightly greater than the improving trend observed for the peak to valley ratio.

4. The preamplifier offset voltages were stable for all eight tested detectors. This indirectly reveals that the leakage currents are stable.

5. The peak channel values were stable for all eight tested detectors indicating the detector/system gain was stable.

For ^{124}Am (59keV):

6. The %FWHM resolution was stable over the 2000-hour test duration for the eight detectors tested.

7. For some of the larger area detectors the peak to valley ratio showed a slight overall improving trend. For two of four of the smaller area detectors a rather large improvement, i.e. an increase in the peak to valley ratio was observed with time

8. In general, the peak to background ratio improved, i.e. increased with time.

9. The preamplifier offset voltages were stable for all eight tested detectors. This indirectly reveals that the leakage currents are stable.

10. The peak channel values were stable for all eight tested detectors indicating the detector/system gain was stable.

For ^{57}Co (122 keV):

11. The %FWHM resolution was stable over the 2000-hour test duration for the eight detectors tested.

12. For the larger area detectors the peak to valley ratio was stable with time. For two of four of the smaller area detectors a noticeable degradation in the peak to valley ratio was observed with time.

13. For the majority of the detectors tested the peak to background ratio displayed a noticeable degradation, i.e. a decrease with time.

14. The preamplifier offset voltages were stable for all eight tested detectors. This indirectly reveals that the leakage currents are stable.

15. The peak channel values were stable for all eight tested detectors indicating the detector/system gain was stable.

These 2000-hour duration life test results demonstrate that HgI_2 gamma-ray detectors possess a high degree of long-term stability in spectral performance.

REFERENCES

1. (to be presented) F.P. Vaccaro, et al., "Elevated Temperature Spectral Performance of HgI_2 Radiation Detectors", *Proceedings of the 12th International Workshop on Room-Temperature Semiconductor X- and Gamma-ray Detectors, Chairman: Ralph James , Nov. 6-9, IEEE Conference 2001, San Diego, Ca.*

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Table 1. 2000 Hour HgI_2 Life Tests: List of Detectors: %FWHM: ^{137}Cs; Initial Conditioned Data and Life Test Results.

Detector #	Detector Area (mmXmm)	Detector Thickness (mm)	2000 Hour Bias Voltage (V)	2000 Hour Bias Electric Field (V/cm)	2000 Hour Preamp Offset Voltage (V)	^{137}Cs (662 keV) %FWHM Original Data	^{137}Cs (662 keV) %FWHM 2000 Hours
80206o11	25X25	2.04	3079	15093	1.40	3.95	4.00
83503b11	25X25	2.32	2955	12737	2.00	3.35	2.80
82404b11	25X25	2.17	2925	13479	1.50	2.90	3.44
83432p11	25X25	2.06	2770	13447	1.85	3.80	2.94
80430a11	10X10	1.70	2869	16876	1.40	3.30	3.55
80430a12	10X10	1.60	1716	10725	0.85	3.60	3.28
82414b13	10X10	1.97	4014	20376	1.48	5.20	4.28
84323a11	10X10	1.52	3215	21151	1.90	5.50	7.70

Table 2. 1000 Hour HgI_2 Life Tests: List of Detectors: %FWHM: ^{241}Am, ^{57}Co; Initial Conditioned Data and Life Test Results.

Detector #	Detector Area (mmXmm)	Detector Thickness (mm)	^{57}Co FWHM% Original Data	^{57}Co FWHM% 1000 Hours	^{241}Am FWHM% Original Data	^{241}Am FWHM% 1000 Hours	Comments
80206o11	25X25	2.04	5.58	5.20	8.39	8.80	Preamp offset voltage increased gradually during life test.
83503b11	25X25	2.32	4.95	4.80	7.80	6.20	Substituted for 81605q11 which failed. Preamp offset voltage increased gradually during life test
82404b11	25X25	2.17	4.50	4.30	6.40	7.90	Preamp offset voltage increased slightly during life test.
83432p11	25X25	2.06	4.90	4.24	7.90	7.99	Preamp offset voltage increased slightly during life test.
80430a11	10X10	1.70	4.90	4.30	7.60	7.10	Preamp offset voltage remained constant during life test
80430a12	10X10	1.60	3.70	3.92	5.00	7.01	Substituted for 8163n11 which failed. Preamp offset voltage remained constant during life test
82414b13	10X10	1.97	5.30	6.22	6.80	9.00	Preamp offset voltage increased slightly during life test.
84323a11	10X10	1.52	8.50	8.60	7.90	13.43	Preamp offset voltage increased slightly during life test.

Figure 1. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors.
^{137}Cs; FWHM%; Area = 625 mm^2; 24 μsec Amplifier Shaping Time.

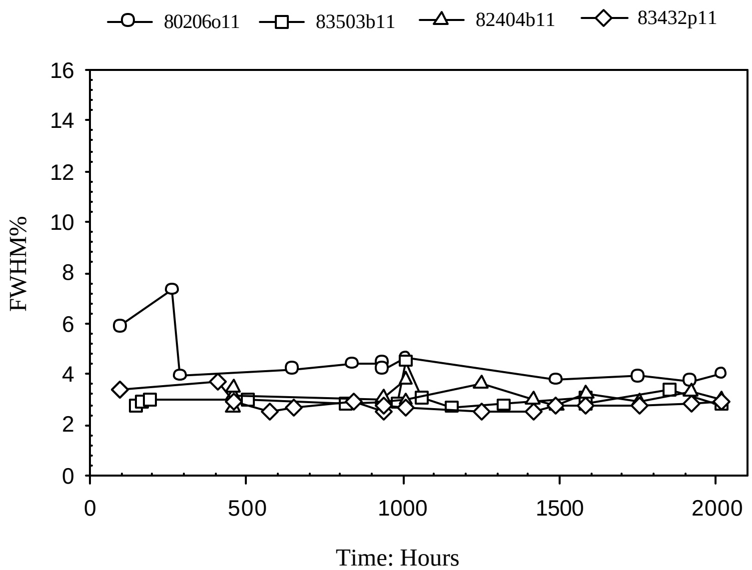

Figure 2. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors.
^{137}Cs; FWHM%; Area = 100 mm^2; 24 μsec Amplifier Shaping Time.

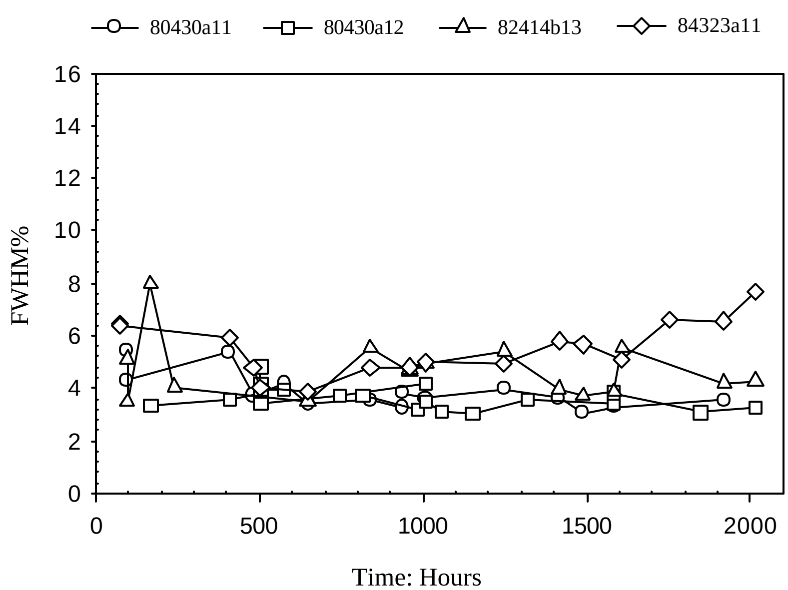

Figure 3. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{137}Cs; Peak/Valley Ratio; Area = 625 mm^2; 24 µsec Amplifier Shaping Time.

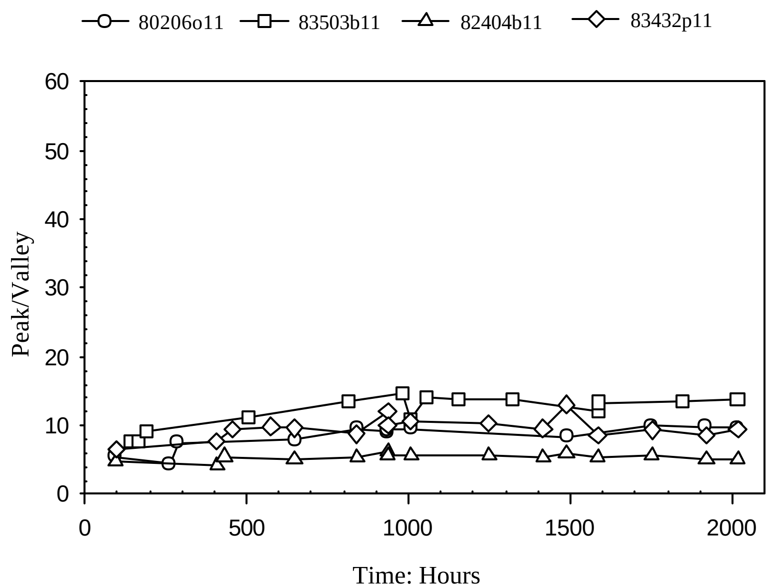

Figure 4. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{137}Cs; Peak/Valley Ratio; Area = 100 mm^2; 24 µsec Amplifier Shaping Time.

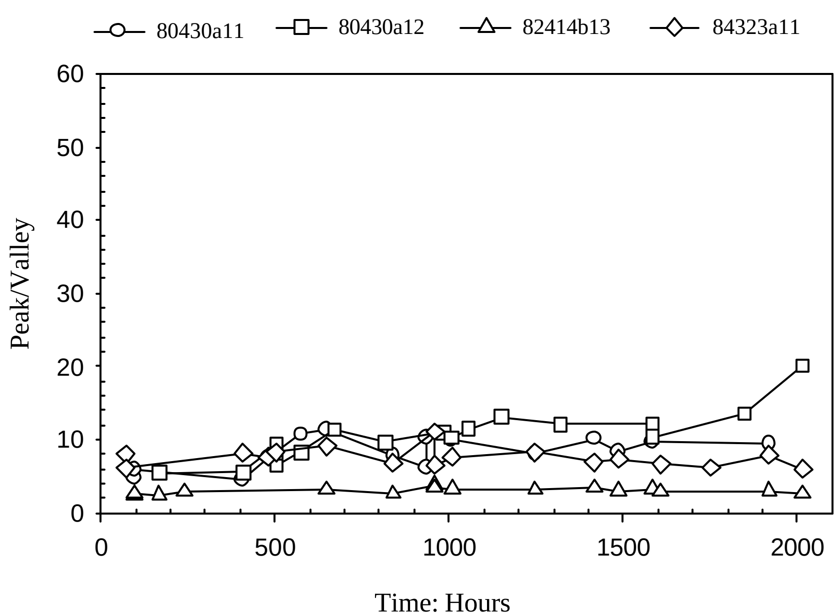

Figure 5. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{137}Cs; Peak/Background Ratio; Area = 625 mm^2; 24 µsec Amplifier Shaping Time.

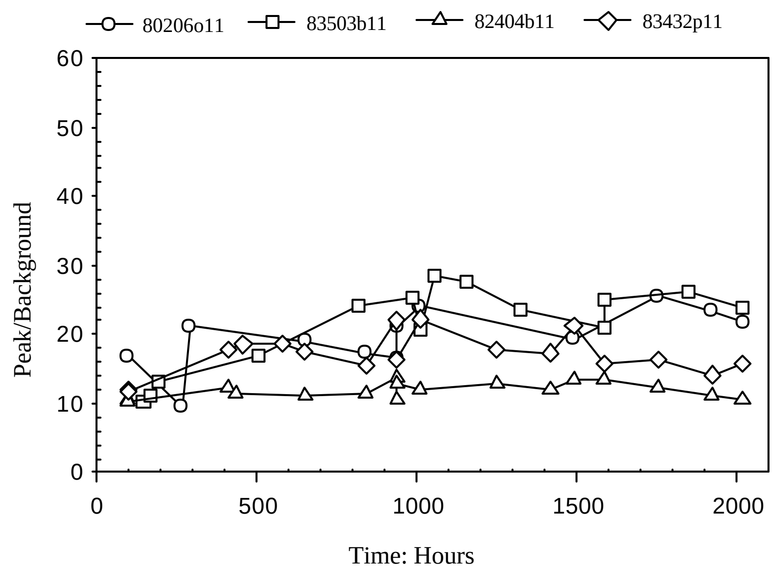

Figure 6. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{137}Cs; Peak/Background Ratio; Area = 100 mm^2; 24 µsec Amplifier Shaping Time.

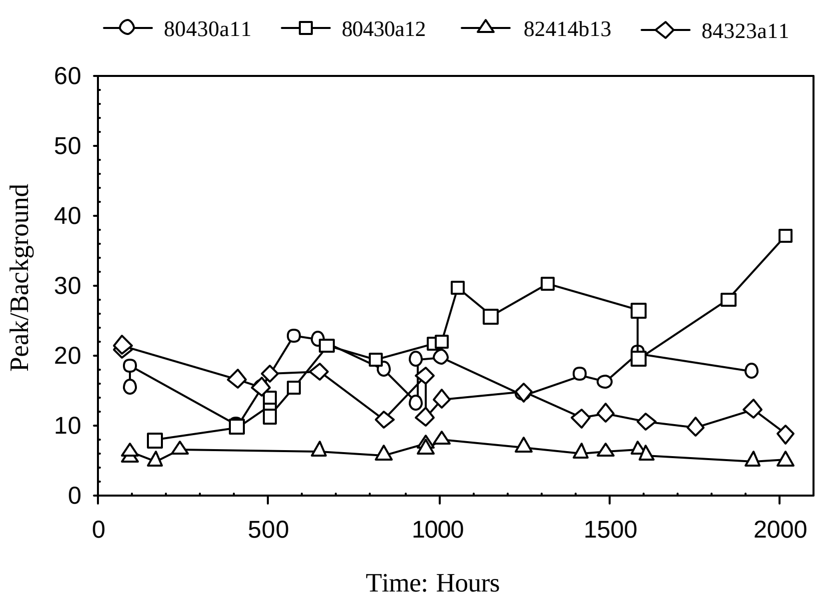

Figure 7. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{137}Cs; Preamp Offset Voltage; Area = 625 mm^2; 24 μsec Amplifier Shaping Time.

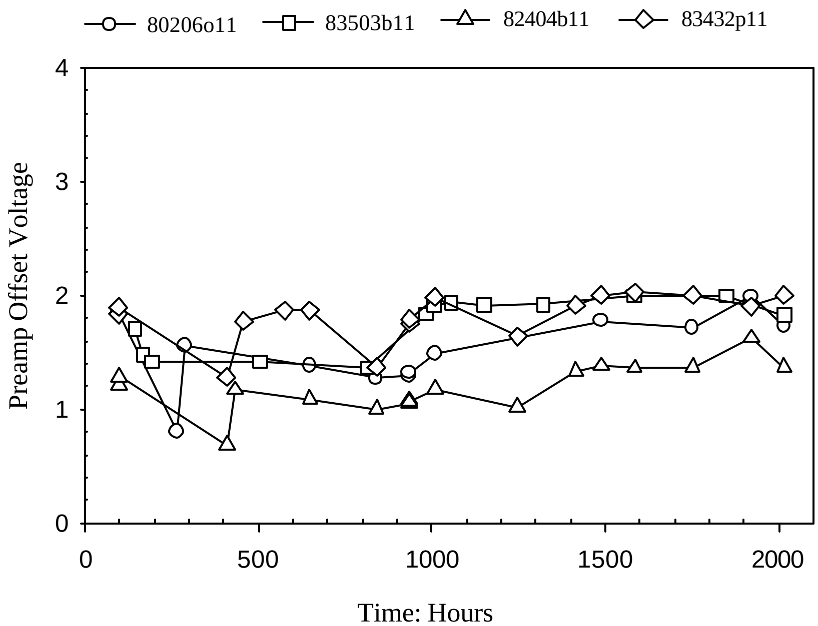

Figure 8. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{137}Cs; Preamp Offset Voltage; Area = 100 mm^2; 24 μsec Amplifier Shaping Time.

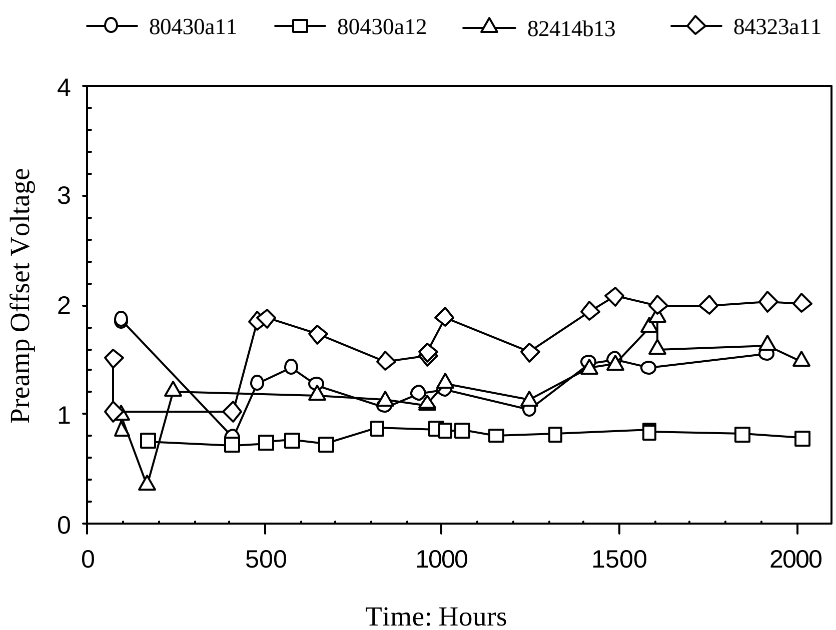

Figure 9. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{137}Cs; Peak Channel; Area = 625 mm^2; 24 µsec Amplifier Shaping Time.

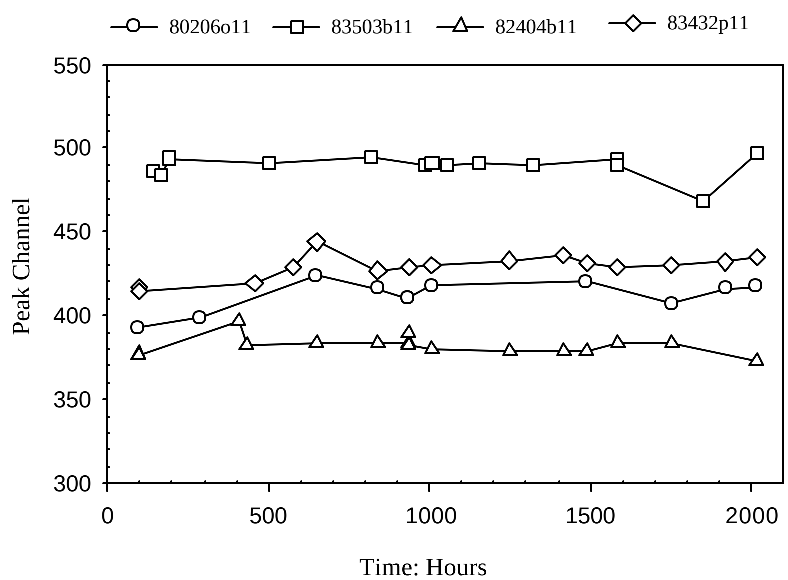

Figure 10. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{137}Cs; Peak Channel; Area = 100 mm^2; 24 µsec Amplifier Shaping Time.

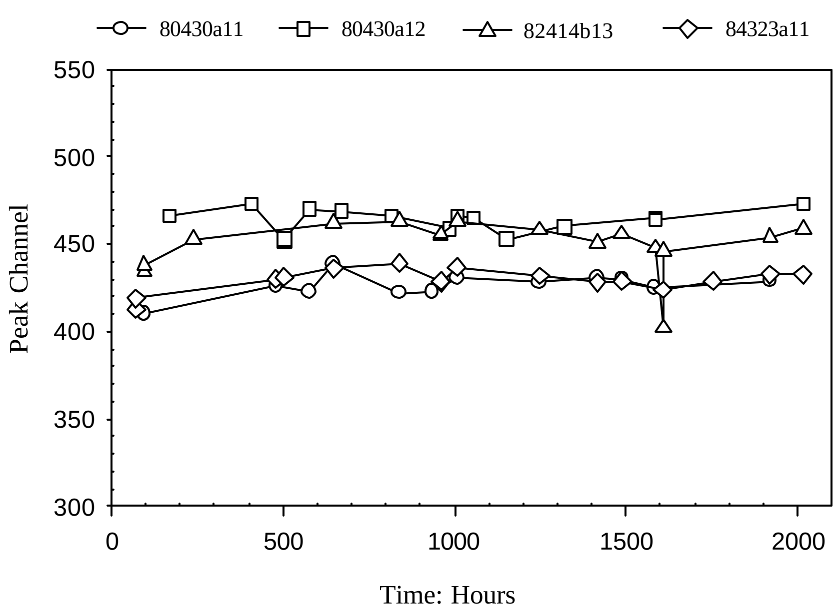

Figure 11. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{241}Am; FWHM%; Area = 625 mm^2; 8 or 12 µsec Amplifier Shaping Time.

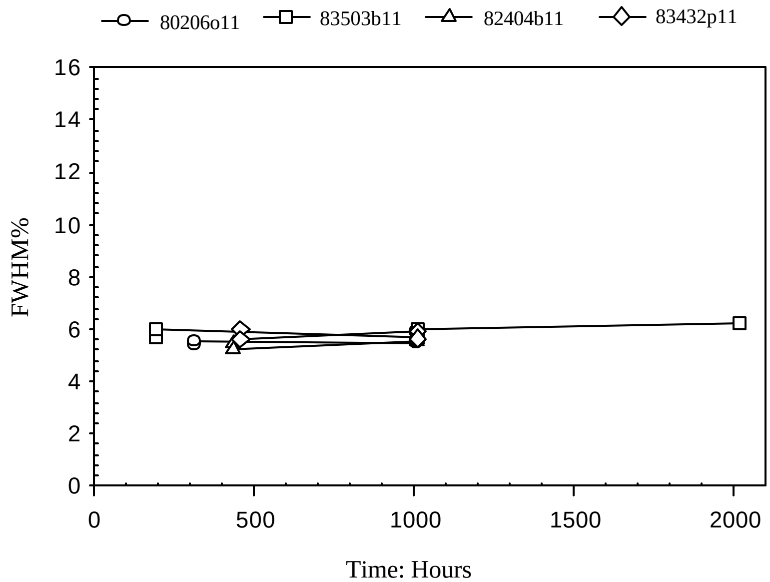

Figure 12. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors. ^{241}Am; FWHM%; Area = 100 mm^2; 8 or 12 µsec Amplifier Shaping Time.

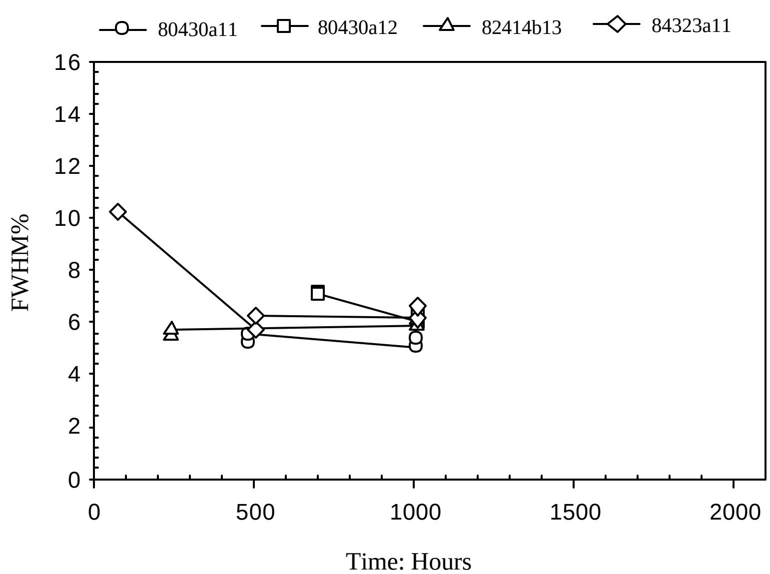

Figure 13. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors.
^{57}Co; FWHM%; Area = 625 mm^2; 8 or 12 μsec Amplifier Shaping Time.

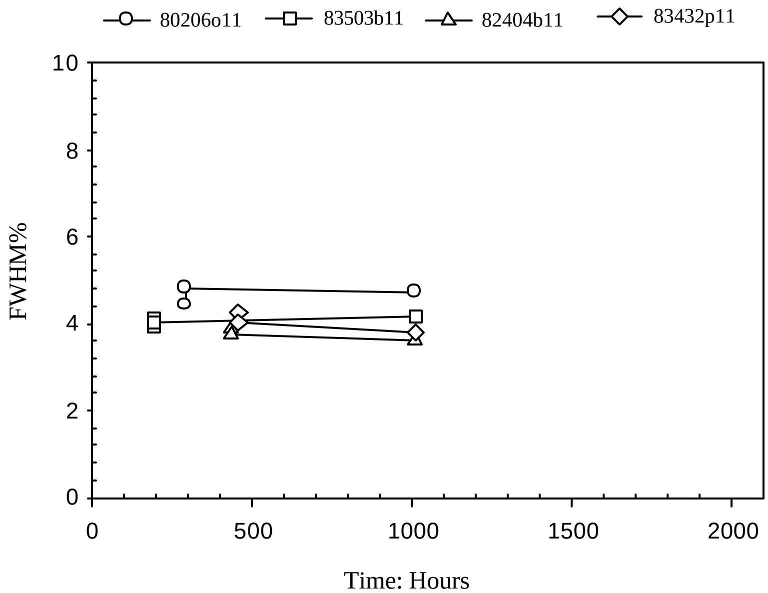

Figure 14. HgI_2 Life Tests: Ambient Conditions. Composite Graph of Four HgI_2 Detectors.
^{57}Co; FWHM%; Area = 100 mm^2; 8 or 12 μsec Amplifier Shaping Time.